A Systematic Review Characterising and Clarifying Intrinsic Teaching Challenges Linked to Inquiry-Based Practical Work

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Abstract

Since scientific literacy has become a key goal in science education, many people have argued in favour of the incorporation of inquiry in science education. However, scattered in the literature are extrinsic and intrinsic teaching challenges linked to the design and implementation of Inquiry-Based Practical Work (IBPW) in secondary school science classrooms. The purpose of this systematic literature review was to characterise and clarify the intrinsic challenges. From an instructional design perspective, the characterisation of the challenges yielded four primary categories. The categories consist of initiation-phase challenges (such as unfavourable views regarding science and practical work), planning-phase challenges (including difficulties involved in designing IBPW), implementation-phase challenges (e.g., persuading learners to reflect on their experiences and findings), and summative evaluation-phase challenges which include concerns linked to the grading of practical inquiry. In the different categories, the challenges are linked to gaps in various aspects of teacher competencies especially in the context of the TPACK framework. The aspects include content knowledge (such as science content and scientific inquiry); in addition to technological knowledge linked to standard technologies. Also included is pedagogic content knowledge (including orientation towards science teaching). Moreover, some of the intrinsic challenges are linked to gaps in skills (including pervasive classroom management and practical skills); in addition to values (such as commitment). These results have theory-, practice-, and research-based implications.

Keywords: inquiry-based; instructional design; intrinsic teaching challenge; practical work; teacher competencies; TPACK

1. Introduction

1.1. Theoretical Background

There have been persistent calls for the science curriculum to mirror the real world needs of learners, in order that they can participate in science-related debates (Lang, Drake, & Olson, 2006). The debates are linked to cloning, global warming, and climate change, for example. Thus, the science education community has recently turned its attention to the concept of scientific literacy. Being the science that the majority of the population will experience, scientific literacy has become a key goal in science education in schools (Ryan, 2009).

There have thus also been calls for the reconstruction of school science in line with the characteristics of scientific inquiry (Ryan, 2009). The characteristics allow for the fostering of human progress through the framing of problems; the formulation of ideas and explanations; and the making of justifiable decisions. Thus, many policy makers, international groups, and reformers (including Department of Basic Education, 2011; European Commission, 2007; Kidman, 2012; National Research Council, 2012, 2013), argue in favour of inquiry-based science education.

This strategy in science education engages learners in such authentic scientific practices as asking questions about the physical world; investigating these questions; and based on empirical data drawn from existing data sources or obtained first-hand, formulating explanations, and justifying assertions (Hofstein & Lunetta, 2004; Quintana et al., 2004). This is in line with the New Generation Science Standards (NGSS Lead States, 2013), which advocates teaching that engages learners in knowledge construction (Miller, Manz, Russ, Stroupe, & Berland, 2018). However, some teachers have concerns linked to safety, time constraints, and the grading of learners engaged in inquiry (Anderson, 2007; Deters, 2004). These concerns could depend on the type of inquiry involved in a given activity. Also, though some studies (such as Klahr & Nigam, 2004), show that inquiry-based science education is less effective than direct instruction in supporting learning, Blanchard et al. (2010) note that a bigger body of research (including Leonard, 1983) shows that inquiry-based teaching and learning is equivalent to or more effective than direct instruction. For example, contrary to the case with traditional science teaching, an argument-based inquiry approach resulted in higher achievement for learners with disabilities (Taylor, Tseng, Murillo, Therrien, & Hand, 2018). Also, 5e (engagement, exploration, explanation, elaboration, and evaluation) inquiry-based lessons resulted in increased goal orientation, an aspect of learner motivation (Mupira & Ramnarain, 2018).

Against the background in the preceding discussion, we focused in the research presented in this paper on practical work. Practical work is an important aspect of science education in most countries (Nivalainen, Asikainen, Sormunen, & Hirvonen, 2010; TIMSS, 1997). However, arguments have been made in favour of the abandonment of practical work for not yielding measurable gains in learner understanding, or for its development, amongst other options (Gott & Duggan, 2007). The research presented in this paper is in line with the development of practical work.

Practical work has been considered to consist of activities which individually or collaboratively engage learners in the manipulation and/or observation of real objects and materials (Millar, 2011). However, practical work also includes experiences that allow learners to interact with data about the natural world that is not necessarily gathered by the learners (National Research Council, 2005a). This aspect of science education goes beyond conventional laboratory activities, as in many situations, computer-based learning (such as using interactive computer simulations), museum-based studies or field work activities could be more effective (Hodson, 1998). It may be worth noting that most of what we refer to in this paper as “practical work” can also be called “laboratory work”. This is based on the fact that in many countries, most secondary school science practical work is carried out in purpose-built laboratories (White, 1988).

Practical work strategies vary along a continuum from a teacher/worksheet-driven to an open-ended learner-driven strategy (Kidman, 2012). The teacher/worksheet-driven strategy has also been referred to as the traditional, ‘cookbook’, recipe-type, verification-based or confirmatory strategy in practical work. This strategy is adequate for developing such basic skills as observation; data collection and organisation; in addition to constructing inferences (Sadeh & Zion, 2012). However, based on this strategy, learners, follow ‘recipes’ in carrying out procedures provided by the teacher, with little thought and purpose (Anderson, 2007). The strategy has also been criticized for not reflecting how scientists work (McComas, 2005). Practical work could be designed in such a way as to enable learners to do science using the practices involved in scientific inquiry (Ottander & Grelsson, 2006). We focused in this study on such practical work which we refer to as Inquiry-Based Practical Work (IBPW).

IBPW consists of experiences in which learners collaboratively manipulate a combination of hands-on and computer-based science education equipment and materials, or existing data sets, in order to gain an understanding of the natural world, while engaging in scientific practices through structured, directed or open inquiry (Akuma, 2017). In this regard, we equate the term “inquiry” to the term “investigation”. Inquiry-based practical investigations (IBPW) should be central in science education and be incorporated in every lesson and concept strand at every level (National Science Teachers Association, 2007).

Research findings show that the learning effects of IBPW are largely positive. The negative findings include a negative effect of student investigations (IBPW) on the science achievement of some adolescents in Qatar (Areepattamannil, 2012) and the fact that investigations are a strong negative predictor of science performance among certain adolescents (e.g., Areepattamannil, Freeman, & Klinger, 2011). However, the positive effects of IBPW have been extensively documented in the science education research literature. For example, IBPW assists learners in the development of a positive attitude toward science and helps in maintaining their motivation (Hofstein & Mamlok-Naaman, 2007; Osborne & Dillon, 2008). Also, learners involved in inquiry laboratories (IBPW) demonstrated a significant improvement in scientific literacy skills (Brickman, Gormally, Armstrong, & Hallar, 2009). In addition, IBPW has the potential to enhance the conceptual understanding, meaningful learning, and understanding of the nature of science (Kipnis & Hofstein, 2008).

1.2. Research Problem, Purpose, and Rationale

Despite the positive effects of IBPW, recipe-type practical work remains prevalent in schools. This is evidenced for example, by the fact that many science teachers still use practical work to only or mostly confirm theory (Childs, Tenzin, Johnson, & Ramachandran, 2012; European Commission, 2007). This is in addition to limiting practical work to teacher demonstrations, or engaging learners in recipe-type practical work (D. Di Fuccia, Witteck, Markic, & Eilks, 2012). In fact, the science laboratory remains a place for conducting routine exercises (Lunetta, Hofstein, & Clough, 2007) in which learners rarely reflect on their methodology and findings (Abrahams & Millar, 2008).

Against the background in the discussion in the preceding paragraph, some researchers have focused on IBPW in secondary school science classrooms. The areas researched include aspects of the IBPW strategy itself, science teacher professional development in this regard, in addition to classroom teaching and learning based on this strategy. Studies in this last aspect include teachers conceptualisation and descriptions of this type of practical work in their classrooms (Gyllenpalm, Wickman, & Holmgren, 2010), and the use of virtual laboratories to promote guided inquiry (Donnelly, O’Reilly, & McGarr, 2013). Also included is the identification of the challenges teachers are confronted with when implementing open inquiry (Zion, Cohen, & Amir, 2007).

Science teachers find it difficult to design inquiry-based lessons (K. S. Davis, 2003), and they also frequently find inquiry-based activities challenging to implement in the classroom (Ritchie et al., 2013). However, B. A. Crawford (2007) noted the lack of a clear picture of the challenges inherent in the implementation of inquiry-based approaches in science classrooms, while Nivalainen et al. (2010) noted the lack of a detailed account of the challenges physics teachers encounter when planning practical work.

Regarding this gap in the literature, and based on a case study of two schools, Akuma and Callaghan (2017) identified teaching challenges that are independent of the competencies (such as knowledge and skills) of physical sciences teachers. This is in relation to the design and implementation of IBPW. The challenges which are extrinsic teaching challenges include the lack of interactive computer simulations in school. Extrinsic and intrinsic challenges are scattered in the international literature on the design and implementation of IBPW in science classrooms in secondary schools. The intrinsic teaching challenges which are challenges linked to the competencies of teachers, include an inadequacy in the pedagogic content knowledge of certain science teachers (Ramnarain, 2016).

In this systematic review of the literature on the design and implementation of IBPW in science classrooms in secondary schools, we focussed on the intrinsic teaching challenges as they were still to be considered in a systemic and explanatory manner. Thus, our purpose was to characterise and clarify the challenges. In a similar effort, Akuma and Callaghan (2016) characterised intrinsic teaching challenges linked to the improvisation of science education equipment and materials in schools. The characterisation was from the point of view of the systematic planning of instruction (i.e., from an instructional design perspective). From this perspective, the intrinsic teaching challenges include preparation- and implementation-phase challenges. Akuma and Callaghan proceeded to clarify the challenges with reference to teacher competencies (such as knowledge and skills). Thus, the systematic review presented in this paper focussed on answers to the following three Research Questions (RQs):

RQ1. What specific intrinsic teaching challenges do some secondary school science teachers face in relation to the design and implementation of IBPW?

RQ2. How can the challenges be characterised from an instructional design perspective?

RQ3. How can the challenges be clarified in relation to teacher competencies?

Herein, these questions are often cited as RQ1, RQ2, and RQ3. That being said, answers to the questions have practice-, and research-based implications. For example, the detailed characterisation of a phenomenon (in this case the intrinsic challenges) helps in providing value and coherence (El-Deghaidy, Mansour, & Alshamrani, 2015), in uncovering knowledge within specific categories (Abell, 2008), in addition to revealing the complexity of the phenomenon and tracking its development (Rozenszajn & Yarden, 2014). Moreover, an understanding of the challenges science teachers are confronted with is needed in order to be able to provide them with appropriate support (Harris & Rooks, 2010). The challenge posed by inquiry-based science teaching (in this case in the context of practical work), can cause teachers to resist or evade curriculum reforms associated with inquiry (Ritchie et al., 2013).

2. Conceptual Framework

2.1. Interconnected Model of Teachers' Professional Growth (IMTPG)

This model from the Teacher Professional Growth Consortium (1994), is the overarching theoretical basis in this study, and is shown in Figure 1.

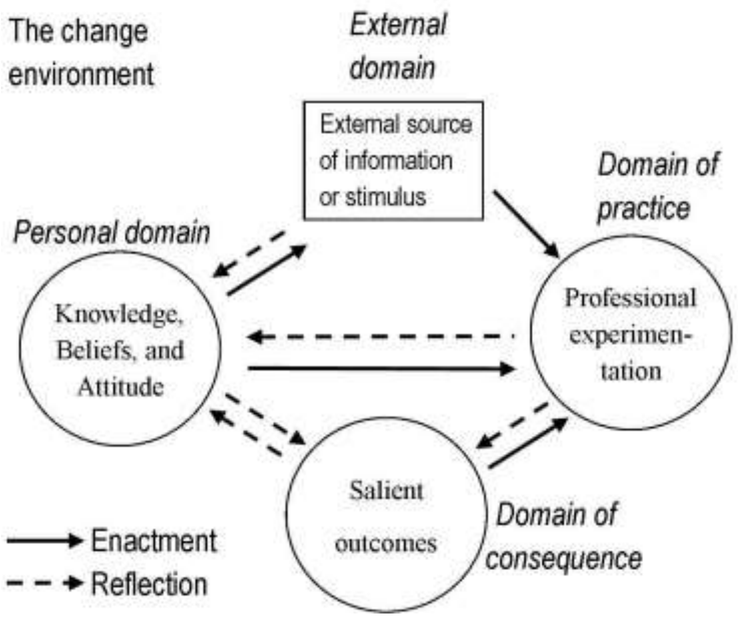

Figure 1 Interconnected Model of Teachers' Professional Growth (Teacher Professional Growth Consortium, 1994)

Based on the IMTPG (Figure 1), effective teacher development occurs in four interacting domains through enactment and reflection. The domains are the external domain which consists of external sources of stimulus, information, and support; the domain of practice which includes classroom experimentation; the domain of consequence containing salient teacher learning outcomes; and the personal domain which consists of teacher knowledge, beliefs, and attitudes.

By experimenting with a new strategy, a change in the domain of practice, a new belief or new knowledge can be developed as a change in the personal domain (Clarke & Hollingsworth, 2002). This development can result in a change in the perception of salient outcomes associated to classroom practice in the domain of consequence. However, there are multiple paths for teacher professional development between the four domains of the model. The development takes place in line with the affordances and constraints being provided by the professional environment (Hollingsworth, 1999).

2.2. Implementation of the IMTPG in this study

2.2.1. Domain of Consequence and External Domain.

We will come to the role of these domains towards the end of this paper. This is due to the fact that their roles are linked to the results of this study.

2.2.2. Domain of Practice and Inquiry-Based Practical Work (IBPW).

This type of practical work is the new strategy that science teachers would have been experimenting with in the domain of practice. We provided a definition of this strategy in the seventh paragraph in the section of the Introduction of this paper titled "Theoretical Background". As we see later within the Methodology section, it is useful to elaborate on the definition.

The Inter-Academy Panel, a global organisation of science academies promotes science education which engages learners in scientific practices such as posing questions, collecting data, arriving at conclusions, and discussing findings (Inter-Academy Panel, 2012). In this light, the National Research Council (2012) identifies eight of these scientific practices that teachers should call upon individually or in combination as needed, in K-12 classrooms. The practices are asking questions; developing and applying models; designing and carrying out investigations; analysing and interpreting data; applying mathematical and computational thinking; formulating explanations; involvement in evidence-based arguments; in addition to acquiring, evaluating, and communicating information.

For incorporating scientific practices in the classroom, in this case during practical work, there are different teaching strategies. The difference among the strategies is the relative amount of learner-driven versus teacher-driven activities that occur during the learning activity. The strategies are contained in Table 1. The first four columns of the table are based on R. L. Bell, Smetana, and Binns (2005) and Schwab (1962). In order to incorporate some of the scientific practices promoted by the National Research Council

(2012) in the description of the teaching strategies, Akuma (2017) added the fifth column of the table. In this study, we have added the practices B and H in this column of the table, in order to incorporate the full range of the scientific practices.

Table 1 Categorisation of inquiry-based strategies in school contexts

Strategy	Question	Methods of investigation	Answers	Scientific practices learners are likely to carry out [a]
0 (Confirmation)	Given	Given	Given	C (ii), D, and E
1 (Structured)	Given	Given	Open	C (ii), D, E, F/F*, G, and H
2 (Directed)	Given	Open	Open	B, C, D, E and F/F*, G, and H
3 (Open)	Open	Open	Open	A, B, C, D, E, and F/F*, G, and H

[a]A = asking questions
B = developing and using models
C = (i) planning and (ii) carrying out investigations
D = analysing and interpreting data
E = using mathematics and computational thinking
F = constructing explanations (F* = drawing conclusions)
G = engaging in evidence-based arguments
H = obtaining, evaluating and communicating information

Structured and directed inquiry is teacher-driven while open inquiry is learner-driven (National Research Council, 2000) as seen in Table 1. With reference to this table, we use the term Inquiry-Based Practical Work (IBPW) in this paper to refer to practical work incorporating one of the inquiry types 1 to 3, as opposed to Type 0 only. We exclude practical work based solely on Type 0 inquiry as we find this type of inquiry identical to the teacher/worksheet-driven strategy in practical work which has been criticised as previously seen in the sixth paragraph of the section titled “Theoretical Background”.

2.2.3. Personal Domain and Intrinsic Teaching Challenges.

Based on the Interconnected Model of Teachers’ Professional Growth (Figure 1), experimentation with IBPW could have led to changes in the personal domain of science teachers. The changes are in relation to professional knowledge, attitudes, and beliefs. However, these areas of teacher competencies are linked to the intrinsic teaching challenges experienced by some science teachers. For example, science teachers need adequate content, general pedagogical and pedagogical content knowledge, in order to be effective in planning practical learning experiences (National Research Council, 2005a). The lack of such knowledge seriously limits the ability of many teachers to teach through inquiry (Capps & Crawford, 2013). However, science teachers can face challenges linked to inquiry due not only to inadequate knowledge, but also skills (Zion et al., 2007). Essential inquiry teaching skills include how to facilitate learners in their inquiry process (B. A. Crawford, 2000). Inadequate professional values also presents challenges to some science teachers (Stephen, 2015). Thus, in this study, we expand the personal domain of the model in Figure 1 to incorporate professional skills and values, in addition to intrinsic teaching challenges.

A teaching challenge refers to a condition (in this case intrinsic) which presents to a science teacher, a difficulty in terms of progressing toward and/or attaining an objective (Schoepp, 2005). The objective in this study is that of the design and implementation of IBPW in science classrooms on a regular basis. This definition can assist in the identification of the inherent intrinsic challenges found in the literature (RQ1). However, in order to be able to characterise (RQ2) and clarify (RQ3) the teaching challenges, we need to further discuss teaching challenges and teacher competencies as seen next.

2.3. Towards Characterising Intrinsic Teaching Challenges Linked to the Design and Implementation of IBPW (RQ2)

Though many categorisations of teaching challenges exist (e.g., Akuma & Callaghan, 2017; Lee, Tan, Coh, Chia, & Chin, 2000; Zion et al., 2007), categorisations of intrinsic teaching challenges are scarce. In one of the few readily available categorisations of intrinsic teaching challenges, Akuma and Callaghan (2016) identified preparation-phase, implementation-phase and assessment-phase challenges. This categorisation which can be extending for the purposes of this study uses an instructional design perspective.

2.3.1. Instructional Design

This deals with the systematic planning of instruction with the aim of making it more relevant and effective (Reiser & Dempsey, 2007). Many instructional design models exist as evidenced by the literature in this regard (e.g., Dick, Carry, & Carry, 2001; Peterson, 2003). However, as an instructional model focussing on practical work, the Science Laboratory Instructional Design (SLID) model (Balta, 2015) is useful here for the purpose of extending the categorisation of intrinsic teaching challenges from Akuma and Callaghan (2016).

2.3.2. The SLID Model

The phases of the SLID model are Initiation, Planning, Execution-guidance-evaluate (herein Implementation), Evaluation, and Feedback (Balta, 2015). The Initiation phase involves analysing learners and content, in addition to setting goals, and selecting a delivery strategy. The strategy could be structured, directed or open inquiry as discussed earlier in relation to Table 1. The choice of strategy which depends on the classroom context and the demands of the content (Blanchard et al., 2010), determines for example, whether learners will be engaged in asking questions (open-inquiry) or planning investigations (directed- or open-inquiry). That being said, teachers typically have as the goal of practical work, to confirm scientific knowledge (considered not inquiry-based in this study), as opposed to being investigative (Ottander & Grelsson, 2006), in this case using the structured, directed or open type of inquiry. This is an example of an Initiation-phase intrinsic teaching challenge linked to IBPW. In the Planning phase, consideration is given to the formation of learner groups, safety precautions, the assessment of needs, the development of assessment instruments, the preparation of learning experiences, in addition to the design and production of materials (Airasian & Russell, 2008; Balta, 2015; Wiggins & McTighe, 1998). We could add to this, the selection of resources including interactive computer simulations. In relation to the preparation of learning experiences and depending on the type of inquiry selected for the

IBPW, the teacher might have for example, to formulate inquiry questions (structured or directed inquiry) and design a valid plan for the investigation (structured inquiry). Regarding the selection of resources, some science educators face challenges in terms of deciding how and when to use interactive computer simulations in practical work (Urban-Woldron, 2009). This is an example of a Planning-phase intrinsic teaching challenge. In the Implementation phase, which brings the teacher and learners together, practical work is carried out in the classroom with the teacher providing guidance and feedback (Balta, 2015). Useful in this regard are learning cycles. They assist science teachers when organising and sequencing inquiry-based learning experiences in the classroom (National Research Council, 2000). Learning cycles include the engagement, exploration, explanation, elaboration, and evaluation (5e) learning cycle (Bybee, 1997). This learning cycle which has achieved considerable success in educational settings (Zuiker & Whitaker, 2014), is well discussed in the instructional design literature (including Rodger W Bybee et al., 2006). For example, in the engagement phase of the cycle, the teacher involves learners in short and simple activities to assess their prior learning; identify any misconceptions that they possess; and promote curiosity. Curiosity is favourable to the asking of inquiry questions by learners for example. However, teachers generally do not provide their learners the opportunity to locate their learning experiences during practical work in the context of their prior learning (Lunetta et al., 2007). This is one example of an engagement-phase intrinsic teaching challenge. That being said, the evaluation phase which extends across the preceding phases as formative assessment, also has a summative assessment component (Bybee, 2009; R.W Bybee et al., 2006). However, the summative evaluation can be carried out within the next phase of the SLID model which is the Evaluation phase. This phase responds to the lack of adequate time during the Implementation phase for learners to report on their practical work. More time is needed for carrying out IBPW than is the case with scripted (confirmation) practical work

(Abrahams & Reis, 2012). That being said, the concerns that many science teachers have regarding the grading of learners involved in inquiry-based learning (Anderson, 2007), in this case during practical work, is an example of an Summative evaluation-phase intrinsic teaching challenge. In the Feedback phase, the teacher could review group formation, the needs assessment, assessment instruments and the delivery strategy as a function of the evaluation of practical work (Balta, 2015).

2.3.3. Resulting Conceptual Framework for Characterising Intrinsic Teaching Challenges

Based on the SLID model, a possible category of intrinsic challenges not included in Akuma and Callaghan (2016) is feedback-phase challenges. Also, considering this model, the preparation-phase challenges category of intrinsic challenges in Akuma and Callaghan, can be split into initiation- and planning-phase challenges. So too is the implementation-phase challenges category which can now be split into the engagement-, exploration-, explanation-, elaboration-, and formative evaluation-phase categories. Thus, we can design the conceptual framework of intrinsic teaching challenges in Figure 2.

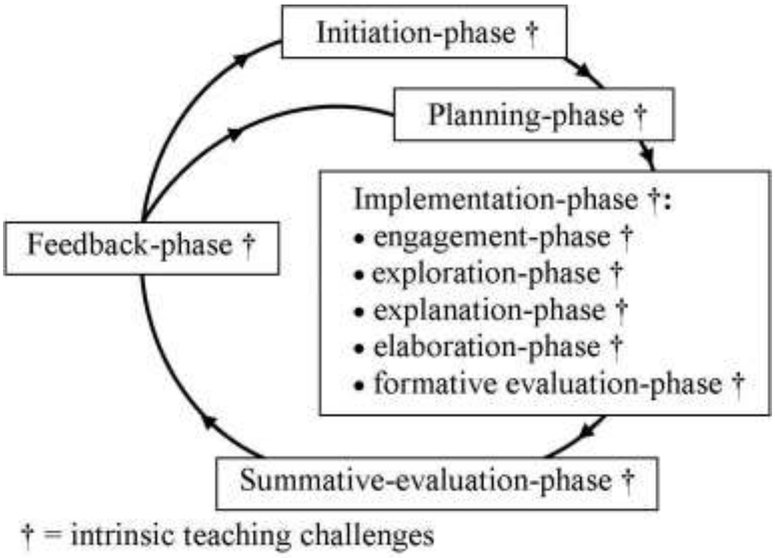

Figure 2 Conceptual framework for characterising intrinsic teaching challenges

Figure 2 could be used to characterise intrinsic teaching challenges linked to the design and implementation of IBPW, in response to RQ2. It remains to consider how the challenges could be clarified across the different categories. This is on the basis of the other components of the personal domain of the Interconnected Model of Teachers' Professional Growth (IMTPG, Figure 1), expanded in this study to include professional skills and values.

2.4. Towards Clarifying Intrinsic Teaching Challenges Linked to IBPW (RQ3)

Teaching challenges could be clarified with reference to the different competencies in the personal domain of the IMTPG. Though some of the competencies are applicable across the different phases of instructional design, certain competencies are linked to specific phases. That being said, teacher competencies include skills, knowledge, understandings, attitudes, motivations, and values (Chong & Cheah, 2009; UNESCO, 2011). Skills include pedagogical, personal, reflective, and management skills (Chong & Cheah, 2009). Chong and Cheah also note that the values that teachers require include concern and care for learners; dedication and commitment to their practice; collaboration and team spirit; in addition to the desire for innovation, excellence, and continuous learning. Most of the enumerated values and skills are needed across the different phases of Science Laboratory Instructional Design (SLID) model. This is similarly the case with certain aspects of teacher knowledge.

The first framework of teacher knowledge was proposed by Shulman (1986) who asserted that teachers need Pedagogical (P) and Content (C) Knowledge (K), now popularly referred to simply as PCK. The PCK concept has been interpreted in several ways and for different purposes in science education research (Appleton, 2003; Park & Oliver, 2008). However, the PCK model of Magnusson, Krajcik, and Borko (1999) has been widely accepted and predominantly used in recent years (e.g., Großschedl, Mahler, Kleickmann, & Harms, 2014).

Based on the Magnusson et al. (1999) PCK model, science teachers possess (or need to possess adequate) knowledge in four main domains. These domains consist of Content

Knowledge (CK), Pedagogical Knowledge (PK), Pedagogical Content Knowledge (PCK), and knowledge of context. Specific factors regarding context include content, grade level and learner background (Doering, Veletsianos, Scharber, & Miller, 2009; Koehler & Mishra, 2009). This knowledge is needed for completing the Initiation phase of the SLID model which includes learner analysis, for example. CK is knowledge about the actual subject matter that is to be taught (Mishra & Koehler, 2006). This includes knowledge of concepts, theories, ideas, organisational frameworks, knowledge of evidence and proof, in addition to established approaches toward developing such knowledge (Shulman, 1986). Thus, CK includes knowledge of scientific and classroom inquiry (National Research Council, 2000). This aspect of CK is needed in the Initiation phase of practical work where a delivery strategy is selected. That being said, teachers' understanding of how science is carried out is critical for implementing inquiry-based projects in the classroom (Akerson, Abd-El-Khalick, & Lederman, 2000). The PK domain includes knowledge of the processes, practices or methods of teaching and learning (Koehler & Mishra, 2009; Mishra & Koehler, 2006). Also included is knowledge of learning objectives; how learning occurs; lesson planning and implementation; in addition to learner assessment (Koehler & Mishra, 2009). Science teachers thus need PK in order to complete the Initiation, Planning, Implementation, and the Evaluation phases in the Science Laboratory Instructional Design (SLID) model.

The interaction between CK and PK yields five PCK components according to the Magnusson et al. (1999) PCK model. The first of these components is orientation towards teaching science, which is knowledge regarding the purpose and goals of science teaching at a given grade level. This knowledge is needed, for example, to complete the Initiation phase of the SLID model which involves goal setting. The second PCK component is knowledge and beliefs about the science curriculum. This component consists of the prescribed goals and objectives, in addition to specific curricular materials and programmes of relevance to science teaching. This knowledge is useful in the Initiation and Planning phases of the SLID model. The third PCK component, knowledge of instructional approaches in science education, includes the knowledge and beliefs of teachers regarding instructional approaches. The fourth PCK component is knowledge and beliefs about the understandings of learners regarding specific topics in science. This includes learner misconceptions, required prior knowledge and topics which present learners with difficulties. Science teachers thus need this knowledge in order to completing the Initiation phase of practical work. The last PCK component, knowledge and beliefs about assessment of science learning, includes knowledge about the aspects of science learning that need to be assessed and how the assessment could be carried out. The teacher needs this knowledge in the formative and summative evaluation phases of practical work.

With the infusion of technology in education, Mishra and Koehler (2006) expanded the PCK concept to yield the TPCK (later TPACK) framework in Figure 3.

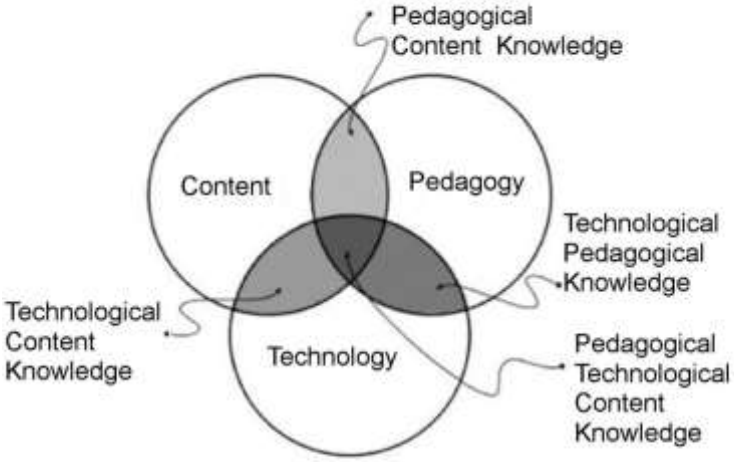

Figure 3 Framework of teacher knowledge (Mishra & Koehler, 2006)

As seen in Figure 3, the addition of Technology (T) to the PCK concept led to four new primary domains of teacher knowledge which we outline below based on Mishra and Koehler (2006). Technological Knowledge (TK) which is knowledge linked to standard technologies (e.g., books) and more advanced technologies (e.g., data loggers and interactive computer simulations), includes the skills needed in order to use particular technologies. That said, Technological Content Knowledge (TCK) is knowledge linked to the reciprocal relationship between technology and content. For example, science teachers need to know not just the science content they teach, but also how this content can be changed by technology. Technological Pedagogical Knowledge (TPK) consists of knowledge of the existence, the elements, and the capabilities of various technologies used in classroom settings, in addition to how teaching might be affected by the use of particular technologies. Finally, Technological Pedagogical Content Knowledge (TPCK) is a form of knowledge that goes beyond all three basic components of teacher knowledge (technology, pedagogy and content). This is the basis of good teaching using technology and includes how technology can be used to teach content in constructive ways. These ways include IBPW as defined in this paper.

Against the background in the preceding discussion of (science) teacher competencies, intrinsic teaching challenges linked to the design and implementation of IBPW could be clarified across the different categories by identifying the associated gaps in the competencies of teachers (RQ3). The identification of the gaps can be achieved by connecting each identified intrinsic challenge to the related teacher competencies.

3. Methodology

In this section of this systematic literature review, we describe how we collected and analysed data. We carried out these activities in a transparent and open-minded manner, in line with Hart (1999). In this light, we describe below, the sequence of steps that we carefully followed in order to ensure the credibility of the study results. The description provides an extensive audit trail, thereby contributing to the confirmability and dependability of the results.

The steps we used in this literature review are in line with Okoli and Schabram (2010) who examined literature reviews in a broad range of domains including the social sciences, and also Henderson, Beach, and Finkelstein (2011), as a good example of a systematic literature review in science education. Specifically, the steps consist of identifying the purpose of the review, identifying articles (searching for the literature), screening for inclusion, the coding of the included articles (quality appraisal), the data extraction and analysis, in addition to writing the review. Thus, we omitted the protocol and training step, due to the fact that this paper was drafted by the first author (F.V.), before being discussed and revised with the input of the second author (R.C.). Peer debriefing with which our discussion commenced contributed in ensuring the credibility and confirmability of the findings of this study. That being said, the purpose of this literature review was to characterise and clarify intrinsic teaching challenges linked to the design and implementation of IBPW in secondary school science classrooms. IBPW is defined previously, in the seventh paragraph of the section of the Introduction titled “Theoretical Background”. Next, we describe the rest of the steps we used this literature review.

3.1. Identifying Articles (Searching for the Literature)

We used only peer-reviewed journal articles that include data on the design and implementation of IBPW in this review. This is because such articles provide the highest quality of data available due to the peer review process used by most journals, and these articles are the type of literature that can most easily be identified using systematic search procedures (Henderson et al., 2011). In this study, we searched the literature twice, first in the latter part of 2016 with a second search carried out in January 2018.

***3.3.1. Initial Database Search*.**

We used a combination of electronic and journal databases. Regarding the journal databases, we used that of three journals that are renowned in the field of science education research, considering their impact factors in relation to other journals in this field. The journals which were also in the Thomson Reuters Web of Science Core Collection (2016) database of journals consist of Journal of Research in Science Teaching, International Journal of Science Education and Journal of Science Education and Technology. However, in order to involve data from other journals in the field of science education research, we used ERIC and Wiley Online Library in the initial database search.

In the searches, we used the following search terms in the full text of articles: “laboratory work” OR “practical work”, “investigative” OR “inquiry-based”, “science education” AND “secondary school”. The use of these search terms which are in line with prior discussions in this paper, was intended to limit the data collection to investigative (inquiry-based) practical work in secondary school science classrooms. That being said, we avoided the terms “challenges” and “intrinsic teaching challenges” in the search terms considering that various terms including “constraints”, “impediments”, “not straightforward”, “hinder” “not easy” and “difficult” have been used in prior research to describe the experiences of teachers when designing and implementing IBPW. Also, we limited the initial search to the period 2007 to 2016. The beginning of this date range (2007) was selected in order to leave about a decade since the National Research Council (1996) put the spotlight on inquiry through the National Science Education Standards. Thereafter, it took years for many countries to infuse inquiry in their science education curricula. Examples are the Netherlands (National Agency for Education, 2000), China (Dai, Gerbino, & Daley, 2011), and South Africa (Department of Education, 2002). Also, there can be a delay of several years between the adoption of a new set of standards and its implementation in the classroom (Pruitt, 2014).

Thus, we estimated that by 2007, many countries around the world would have begun implementing inquiry in their classrooms, and that research outcomes in this regard could then be readily available. Though the end of the date range in the initial database search was set to 2016, which is when the search was conducted, the date range for the second database search goes beyond this date as seen subsequently. In the case where we obtained more results in a particular search, we considered only the first 25 results in order of relevance. Though this number was arbitrarily chosen, we wanted only articles that were more tightly focused on the design and implementation of IBPW in secondary school science classrooms. Secondly, truncating the results in this way was in the minority of the database searches, though this made the search to be not exhaustive for the particular databases. In addition to the above five online databases, and similar to Ward (2016), we also searched a database of articles from our previous systematic literature reviews on a similar subject.

Based on the search criteria presented in the preceding paragraph, the number of articles retrieved in the initial online searches was 67 while the number of articles from the database of articles in our previous systematic literature reviews was 21. This gives a total of 88 articles. However, 10 articles were duplicates leaving 78 unique articles in the initial search list.

***3.1.2. Second Database Search*.**

We used a seventh database, Google Scholar, in the search which we carried out in January 2018. This time, we set the date range from 2007 to 2017 and did not restrict the number of items in the search results. The extension in the date range and the removal of the restriction on the number of items in the search results was intended to expand the data collection. On this basis, the search yielded 162 items which included doctoral thesis, books, conference papers, in addition to peer-reviewed journal articles. The articles which were the only sources of interest in this study, as previously explained in the beginning of the section titled

“Identifying articles …” (para. 1), were 35 in number. However, one of these articles was a duplicate of an article identified in the initial database search. This leaves 34 articles in this second search list.

In identifying articles in this second database search, like in the initial database search, the data collection methods and the location of the studies presented were not used as exclusion criteria, in line with the systematic nature of this literature review.

3.2. Screening the Search List

We carried out a preliminary review of the articles in the search lists. Criteria used in the review of the 78 articles in the first search list consist of the alignment of the articles with the date range for the database search (2007-2017) and the purpose of this systematic literature review. On this basis, we excluded six articles that though in the search list, where published before 2007 (e.g., Lewis, 2006). Some among these six articles may also not have been in line with the purpose of this literature review as was the case with many of the remaining articles. They included two on post-secondary science education (such as Bouzidi & Jaillet, 2009). We also excluded three articles that did not include a definition or description of the practical work involved (e.g., Borrows, 2008) as any intrinsic teaching experiences contained in these articles cannot necessarily be associated with IBPW. We also excluded 23 articles on studies focussing mostly or only on learners (e.g., Kawalkar & Vijapurkar, 2015), ten articles focussing on elementary (primary) science teachers (e.g., Martin & Hand, 2009), and fourteen articles on pre-service science teachers (e.g., B. A. Crawford, 2007). Also excluded was an article on instrument development (Campbell, Abd-Hamid, & Chapman, 2010) and two articles comparing strategies involving practical inquiry and expository instruction (e.g., Pinar & Ceren, 2008). Thus, 60 articles were excluded, leaving 17 of the initial 78 articles in the initial search carried out in 2016.

We also subjected the 34 journal articles resulting from the second database search carried out in 2018 to exclusion criteria similar to the criteria in the discussion in the preceding paragraph. In this light, we excluded an article which was published before 2007 (Barton, 2005), another article focussing not on IBPW specifically, but on practical work in general (Abrahams & Reis, 2012), and a third article for involving practical constraints linked to inquiry-based pedagogy in general and not IBPW specifically (Dai et al., 2011). Though Khan (2011) involved IBPW using computer simulations, we excluded this article as it focused on the post-secondary educational level. We also excluded three articles focussing on various aspects other than teaching and learning during IBPW (e.g., the standards, Pruitt, 2014), in addition to five articles for focussing on learners (e.g., the learning outcomes of IBPW, Areepattamannil, 2012). We further excluded four articles (including B. A. Crawford, 2007) whose participants were pre-service secondary school science teachers. This was in addition to the six articles from studies in primary/elementary schools that we also eliminated (e.g., Ødegaard, Haug, Mork, & Sørvik, 2014). In the final analysis, we could retain only 12 articles from the second search list. This takes the total number of peer-reviewed journal articles included in this literature review to 29.

3.3. Coding

We coded the 29 included articles on five aspects. The first two aspects which help in verifying the suitability of the included articles for this literature review, consist of the inquiry type involved in practical work (structured, directed, and open inquiry) and the scientific practices (such as asking questions and constructing explanations) incorporated. The third aspect in the coding which was the data collection method(s) used is indicative of the overall quality of the data gathered. The last two aspects are the study location and the science subject (s) taught by participating teachers. These provide information about the comprehensiveness of the included studies. That being said, the coding sheet containing details regarding these five aspects is found in the Appendix.

The first row of the Appendix identifies the 29 articles included in this literature review. The majority of the articles combined at least two methods of data collection, thereby incorporating methodological triangulation and ensuring the credibility and dependability of the research findings on which the present article is based. As seen in the second row of the Appendix, the individual methods consist of interviews (16 articles), observation (11), artefacts (9), survey (7), learner assessment (4), field notes (1), and a literature review (7). Essentially, 22 of the articles were empirical studies, while the remaining seven were literature reviews (and are coded h in the second row of the Appendix). The seven review articles and the literature in the 22 empirical studies, provided data from prior studies outside the articles directly included in this literature review. One of the literature review articles (Zion & Mendelovici, 2012) included the description of an instructional sequence involving IBPW.

In relation to study location, the 22 empirical studies and the one literature review which included the description of an instructional sequence involving IBPW, took place in North America (3 articles), Europe (5), Africa (6), Asia (7), and Oceania (2). The study location for individual articles is contained in the third row of the Appendix. Regarding the science subject (s) taught by the teachers who participated in the empirical studies, these include Biology (6 teachers), Chemistry (6), Physical sciences (6), Physics (2), and other sciences including Environmental sciences, Life sciences and Natural sciences (4). Details in this regard are found in the fourth row of the Appendix. The coding thus verifies the comprehensive nature of the included articles, in terms of study location and the science subjects that participants taught. The comprehensiveness ensures the transferability of the findings of this study in relation to educational setting and science discipline taught.

As seen in the fifth row of the Appendix, three types of inquiry were involved in the 22 empirical studies and the one literature review which included a description of an instructional sequence involving IBPW. The types of inquiry are structured, directed, open inquiry or a combination of these types of inquiry. The number of times that structured, directed, and open inquiry was involved is 5, 14 and 12 respectively.

All the empirical studies incorporated two to seven different scientific practices in practical work, as seen in the sixth row of the Appendix. The number of times a particular scientific practice was incorporated in practical work ranged from two (engaging in evidence-based arguments) to nineteen (planning investigations). The incorporation of scientific practices in practical work and the use of the different types of inquiry in practical work is evidence of the suitability of the included articles for this review of the literature on the design and implementation of IBPW.

3.4. Data Extraction and Synthesis (Data Analysis)

This regard, we proceeded in three phases consisting of the data extraction and two phases of data analysis. We used two phases in the data analysis in the sense that we combined the deductive *a priori* template of codes approach in thematic analysis (Crabtree & Miller, 1999) and the data-driven inductive approach (Boyatzis, 1998).

3.4.1. Data Extraction

By reading the full text of the 29 included peer-reviewed articles in detail, we identified specific challenges linked to the design and implementation of IBPW. The identification of these challenges was based on the definition of a teaching challenge from Schoepp (2005) that we earlier presented just before the section titled “Towards characterising intrinsic teaching challenges …”. The challenges could be identified from teacher experiences described using terms such as “impediments”, “constraints”, “not straightforward”, “not easy”, “restrictions”, “hinder”, and “difficult”. However, only challenges linked to the competencies (such as the knowledge and skills) of individual teachers (intrinsic challenges) were considered, in line with RQ1. The challenges were extracted per article for all the 29 articles included in this literature review. If the challenge was presented in the Results section of the included article, the challenge was attributed to the authors of the article. However, if the challenge was presented in the literature contained in the article, the challenge was attributed to the cited source. The first column of Table 2 contains six examples of intrinsic teaching challenges linked to IBPW that we extracted.

Table 2 Illustrating the characterisation of the intrinsic challenges

Example of intrinsic teaching challenge linked to IBPW[a]	Deductively generated category	Inductively generated category
i. Some science teachers possess an orientational framework characterized by a focus on subject-specific requirements and an emphasis on learning scientific content (Ruhrig & Höttecke, 2015) ii. Views of teachers regarding nature and goal of practical work influences the strategy they choose (Ramnarain & Schuster, 2014)	Initiation-phase	Unfavourable orientational framework and views regarding nature and goals of science
iii. Degree of a teacher’s self-confidence in teaching inquiry is a factor in choosing a strategy (Ramnarain & Schuster, 2014)		Prioritization of subject matter and lack of confidence in implementing inquiry
iv. Formulating inquiry questions is difficult for teachers (Van der Schee & Rijborz, 2003)	Planning-phase	Difficulties involved in designing IBPW
v. Teachers generally do not give learners the opportunity to situate learning experiences in the context of their prior learning (e.g., Abrahams & Millar, 2008)	Primary: Implementation-phase Secondary: Engagement-phase	Situating new learning in the context of prior learning
vi. Teachers often face difficulties in helping learners ask thoughtful (researchable) questions and in designing their own investigations (e.g., R.M Schneider, 2013)	Primary: Implementation-phase Secondary: Exploration-phase	Persuading learners to engage in inquiry

[a] IBPW = Inquiry-Based Practical Work

Table 2 is useful in illustrating the subsequent description of the analysis of the extracted data.

3.4.2. Deductive Component of the Data Analysis

In line with the deductive *a priori* template of codes approach in thematic analysis, we defined *a priori* categories of intrinsic challenges linked to the design and implementation of IBPW, based on Figure 2. The primary categories consisted of initiation-phase challenges, planning-phase challenges, and implementation-phase challenges, for example. Under the implementation-phase challenges category, the secondary *a priori* categories included engagement-phase challenges and exploration-phase challenges.

Each intrinsic challenge was then assigned to the appropriate primary and secondary category of teaching challenges. For example, the first three examples of challenges in Table 2 were assigned to the initiation-phase challenges *a priori* primary category. While the fourth example was assigned to the planning-phase challenges category, the last two were respectively assigned to the engagement-phase and exploration-phase *a priori* secondary categories of challenges, which fall under the implementation-phase challenges *a priori* primary category. The assignment of all the extracted challenges as described, allowed us to proceed inductively in the analysis of the data within each of the *a priori* categories.

3.4.3. Inductive Component of the Data Analysis

For this component, the method of constant comparison (Strauss & Corbin, 1990) was used. In doing so, each intrinsic challenge in an *a priori* category was coded as a category. The codes were then compared with each other within the category. This led to inductively-generated categories of intrinsic teaching challenges within certain *a priori* categories of challenges. For example, the first two examples of the challenges in Table 2 fall under different inductively generated categories. These categories encompass other similar examples of challenges as seen subsequently in the section titled “Initiation-Phase Challenges and their Clarification”.

In the manner described in the discussion in the last three preceding paragraphs, intrinsic challenges linked to the design and implementation of IBPW in the literature could be deductively then inductively characterised (RQ2). However, the intrinsic challenges in the different categories needed clarification (RQ3). In order to do so, we considered each individual challenge against the basis for clarifying intrinsic challenges earlier presented in the section titled “Towards Clarifying Intrinsic Teaching Challenges ...” On this basis, the clarification consisted of identifying the corresponding gap (s) in teacher competencies. For example, in relation to the first initiation-phase challenge in Table 2, some teachers could have a gap in their CK considering that this knowledge includes knowledge of evidence and proof, in addition to established approaches toward developing such knowledge. CK also includes knowledge of scientific and classroom inquiry. The teachers could also have gaps in their PK in terms to orientation towards teaching science.

4. Results

In this section, and in response to RQ1, we present eleven primary intrinsic teaching challenges linked to the design and implementation of IBPW based on our literature review. Considering RQ2, we have characterised (categorised) the challenges based on Figure 2. In each of the different categories, we have clarified each intrinsic challenge right after presenting the challenge, in response to RQ3. We first present these results in a nutshell in Table 3.

The first two columns of Table 3 show categories of intrinsic teaching challenges linked to the design and implementation of IBPW in secondary school science classrooms (RQ2). The individual challenges (RQ1) are shown in the third column of the table, with the last column containing the clarification of the different intrinsic challenges in terms of gaps in teacher competencies. In the rest of this section, we present details regarding the results contained in Table 3.

Table 3 Characterisation and clarification of intrinsic challenges linked to inquiry-based practical work

Phase of instructional design		Intrinsic challenge	Clarification: Gap in …
Initiation		1. Unfavourable orientational framework coupled with views regarding science and practical work 2. Prioritization of subject matter and lack of confidence in implementing inquiry	- CK (e.g., of evidence and proof and of scientific and classroom inquiry) - PCK (of orientation towards teaching science, and of knowledge and beliefs about the science curriculum)
Planning		3. Difficulties involved in designing IBPW	- CK (e.g., of evidence and proof , of scientific and classroom inquiry, and laboratory techniques)
		4. Inadequacies linked to equipment improvisation	- TK of standard technologies - PCK (of curricular materials) - Practical skills - Values (e.g., commitment)
Implementation	Engagement	5. Situating new learning in the context of prior learning	PCK (linked to understanding learners)
	Exploration	6. Persuading learners to engage in inquiry 7. Need to keep learners on task and on pace 8. Providing adequate learner support	- PCK (of instructional approaches) - Skills of pervasive classroom management - CK (e.g., planning and conducting inquiry), investigative skills
	Explanation	9. Persuading learners to reflect on their experiences and findings	- CK (science concepts, scientific and classroom inquiry) - PCK (instructional approaches)
	Formative evaluation	10. Engaging in formative teacher-learner interactions	- Sound CK - Significant experience in science teaching
Summative evaluation		11. Concerns and difficulty linked to the grading of practical inquiry	PCK (linked to assessment)

4.1.Initiation-Phase Challenges and their Clarification

4.1.1. Unfavourable Orientational Framework and Views Regarding Science and Practical Work

Some science teachers possess an orientational framework that is characterized by a focus on subject-specific requirements and an emphasis on learning scientific content (Ruhrig & Höttecke, 2015). Such a framework might hinder learning about the epistemic role of evidence in science. Also, teachers with the view of science as an accumulation of knowledge tend to teach by following the textbook and emphasize getting the right answers (Lin & Chen, 2002). That being said, the views of teachers regarding the nature and goal of practical work influences the strategy they choose (Ramnarain & Schuster, 2014). Specifically, teachers who consider practical work as an activity to confirm scientific concepts and laws that have been taught, are more likely to choose the active direct (confirmatory) strategy, while teachers who see practical work as an experiential ground for learning science concepts are likely to choose inquiry-based strategies (structured, directed or open inquiry). The views of teachers regarding subject matter can also shape their conceptions of inquiry, and subsequent use of inquiry in the classroom (Trumbull, Scarano, & Bonney, 2006).

4.1.2. Prioritization of Subject Matter and Lack of Confidence in Implementing Inquiry

It also appears that even when the teachers believe in the goals and effectiveness of inquiry-based teaching, their practices may be driven more by the prioritization of the mastery of subject matter than by the development of the investigative skills of their learners (Dudu & Vhurumuku, 2012). In addition, the degree of self-confidence in teaching inquiry that a teacher possesses is a factor in their choice of the strategy for implementing practical work (Ramnarain & Schuster, 2014). In this regard, some teachers cite the lack of the experience and the expertise they need in order to move away from the confirmatory strategy in practical work.

The results in the last two preceding paragraphs suggest that some teachers could be lacking in the fact that Content Knowledge (CK) includes knowledge of evidence and proof, in addition to established approaches toward developing such knowledge. CK also includes knowledge of scientific and classroom inquiry. Otherwise, or in addition, the teachers could have gaps in the pedagogical content knowledge (PCK) components orientation towards teaching science, in addition to knowledge and beliefs about the science curriculum.

4.2. Planning-Phase Challenges and their Clarification

4.2.1. Difficulties Involved in Designing IBPW

Finding genuinely open-ended problems suitable in investigations in school classrooms could be difficult (Kind, Kind, Hofstein, & Wilson, 2011). However, the formulation of inquiry questions is a difficult task for teachers (Van der Schee & Rijborz, 2003; Zion & Mendelovici, 2012). Also, teachers in schools in diverse socio-economic backgrounds acknowledged lacking competence in the formulation of hypotheses (Ramnarain, 2014). In addition, teachers have difficulties in understanding concepts of evidence such as identifying and setting up controls, and designing reliable and valid plan for the (structured) inquiry, including determining constant factors and the need for repeatability (Zion et al., 2007).

This challenge could be due to a gap in the CK regarding evidence and proof, in addition to established approaches in the development of scientific knowledge. This includes knowledge of scientific and classroom inquiry. A lack of procedural knowledge, and specifically knowledge of laboratory techniques, has been suggested as a hindrance to the ability to conceive, imagine, and design scientific experiments (Séré, 2002).

4.2.2. Inadequacies Linked to Equipment Improvisation

There are shortages, hazards and adverse environmental effects linked to certain conventional science education equipment and materials (Ens et al., 2012; Poppe, Markic, & Eilks, 2011; Singh & Singh, 2012). Though improvised equipment (e.g., micro-scale experiments and self-created models) are useful in providing learners with inquiry-based practical experiences (Schmidt, 2003), some teachers in ill-equipped classrooms lack the motivation, the creativity, or have inadequate skills in the production and/or use of improvised equipment in practical work (Bhukuvhani, Kusure, Munodawafa, Sana, & Gwizangwe, 2010; Kadzera, 2006; Stephen, 2015). These challenges indicate a shortfall in teachers' technological knowledge

(TK) of standard technologies and/or PCK relating to curricular materials, in addition to inadequate practical skills and values (e.g., commitment).

4.3. Implementation-Phase Challenges and their Clarification

4.3.1. Engagement Phase

Situating new learning in the context of prior learning

From a socio-cultural perspective, learners construct new knowledge on the basis of their prior learning (Garbett, 2011). However, teachers generally do not give learners the opportunity to situate their learning experiences during practical work in the context of their prior learning (Abrahams & Millar, 2008; Lunetta et al., 2007). This challenge suggests a gap in the PCK linked to the understanding of learners.

4.3.2. Exploration Phase

Persuading learners to engage in inquiry

Teachers need to give learners opportunities to pose questions, to formulate hypotheses and design experiments to seek answers to their questions (e.g., Neber & Anton, 2008; Ottander & Grelsson, 2005). However, teachers seldom engage their learners to formulate questions and the hypothesis to investigate, in addition to planning the experimental procedure needed (e.g., Chin & Osborne, 2008; Ottander & Grelsson, 2006). Thus, Kind et al. (2011) observed that more than 80% of the time learners involved in practical work focused on data gathering. Actually, teachers often face difficulties in relation to helping learners in the asking of thoughtful (researchable) questions and in designing their own investigations (Marx, Freeman, Krajcik, & Blumenfeld, 1998; R.M Schneider, 2013). This challenge is linked to a gap in the PCK associated to instructional approaches.

Need to keep learners on task and on pace

Teachers tend to focus more on learners completing the practical activity than on enhancing their understanding (Donnelly et al., 2013). Specifically, teachers often find themselves monitoring learners during group work to ensure that the learners are on task and on pace for completing work, leaving little time to address the science ideas meant to be at the forefront of investigations (Holbrook & Kolodner, 2000). Thus, often times, essential science ideas are rather addressed in a whole-class discussion following the group work and sometimes when this work extends too long, there is limited time at the end of the lesson to fully address the science ideas. In this regard, skills of pervasive management of science classrooms could be useful (Harris & Rooks, 2010).

Providing adequate learner support

Teachers find it challenging to decide when to provide support and when to hold back information in order to promote authentic inquiry learning (B. A. Crawford, 2007; Furtak, 2006). This includes how much to lead learners in the formulation of a research question (Trumbull et al., 2006). The challenge could be indicative of a shortfall in teacher's CK linked to inquiry (such as types of inquiry-based strategies). Also, teachers sometimes lack the CK that they need in order to recognize good questions, relevant variables, adequate data analyses, or to help their learners to gain the background knowledge necessary to develop good inquiries (Carlsen, 1993). Also, teaching a class where learners are involved in investigations (IBPW), requires a deep understanding of science practices (thus CK associated to scientific inquiry) and investigative skills, in order to guide learners in the formulation of research questions and in the planning of investigations (National Research Council, 2005a). The inadequacy could be due to a gap in the CK of evidence and proof, as well as established approaches toward developing scientific knowledge (scientific inquiry).

4.3.3. Explanation Phase

Persuading learners to reflect on their experiences and findings

In order to guide learners in their inquiry efforts, teachers need to press them to explain, justify, critique, and revise their ideas as they examine their experiences with phenomena (R. M Schneider, Krajcik, & Blumenfeld, 2005). However, teachers seldom challenge learners to reflect on their observations (Abrahams & Millar, 2008) or engage in manipulating the data that they have collected (Ottander & Grelsson, 2006). For example, Donnelly et al. (2013) observed in a case study of four science teachers that three consider the analysis and critiquing of the findings of an experiment as an add-on to practical work and not an integral part of it. Thus, very little lesson time, if any, is given to the discussion of findings during the course of an experiment. In fact, supporting science learners in making sense of their experiences is difficult especially for teachers new to inquiry-based pedagogy (R.M Schneider, 2013). Teaching a class where student investigations (IBPW) are incorporated, requires a deep understanding of the science concepts (CK) needed in order to guide the learners towards an understanding of the subject matter (National Research Council, 2005b). However, the challenge of persuading learners to reflect on their experiences and findings could also be due to a gap CK regarding classroom and scientific inquiry and/or PCK linked to instructional approaches.

4.3.4. Formative Evaluation Phase

Engaging in formative teacher-learner interactions

On-going formative assessment may assist in enhancing the awareness of science teachers regarding the needs and capabilities of their learners (National Research Council, 2005a). In this regard, the questions that learners ask are potentially useful (B. Bell & Cowie, 2001) as these questions provide insights into their puzzlement, knowledge and understanding, thus acting as a window into their minds (Chin & Osborne, 2008). However, formative assessment is still rare in most classrooms (Ruiz-Primo & Furtak, 2007). Posing questions to learners and dealing with their questions has been shown to be one of the difficulties teachers encounter when managing inquiry-based instruction (Furtak, 2006). It is also a challenge to provide learners with constructive comments (Zion & Mendelovici, 2012). In addition, on-going and active assessment of the thinking and ideas of learners can be challenging when leaners are engaged in investigations in multiple groups (Harris & Rooks, 2010). A sound CK and how it is constructed is needed for formative interactions between a teacher and learners (Moreland, Jones, & Northover, 2001). In addition to considerable content knowledge, a teacher needs significant science teaching experience in order to ask higher-level cognitively based questions of the type that support student learning (Chaney, Hammer, Sander and Rivers cited in National Research Council, 2005b). Thus, the teaching challenges associated with engaging in formative teacher-learner interactions could be due to a gap in the CK in addition to the lack of science teaching experience.

4.4. Summative Evaluation-Phase Challenges and their Clarification

4.4.1. Concerns and difficulty linked to grading practical inquiry

Many science teachers either have concerns regarding the grading of learners involved in inquiry-based learning (Anderson, 2007) in this case during practical work or actually find the assessment of IBPW difficult (Higgins, 2009; Zion & Mendelovici, 2012). At the same time, though ways exist for doing so, these are rarely used (D.-S. Di Fuccia & Ralle, 2006, 2010). This can be due to a gap in teachers’ PCK linked to assessment.

5. Discussion and Conclusion

The purpose of the systematic literature review presented in this paper was to characterise and clarify intrinsic challenges linked to the design and implementation of Inquiry-Based

Practical Work (IBPW) in secondary school science classrooms. IBPW consists of experiences in which learners collaboratively manipulate a combination of hands-on and computer-based science education equipment and materials, or existing data sets, in order to gain an understanding of the natural world, while engaging in scientific practices through structured, directed or open inquiry (Akuma, 2017). The results indicate that the design and implementation of IBPW is plagued by a range of intrinsic teaching challenges occurring in four primary categories. The categories consist of initiation-phase, planning-phase, implementation-phase, and summative evaluation-phase challenges, as seen in the first three columns of Table 3. We have clarified these challenges in relation to teacher competencies, especially with reference to the TPACK framework of teacher knowledge previously presented in the section titled "Towards Clarifying Intrinsic Teaching Challenges ..." On this basis, we found that the challenges are linked to gaps in the knowledge, skills and values of science teachers as seen in the last column of Table 3. The gaps in knowledge include those linked to CK and PKC. These knowledge domains have a large impact on teaching effectiveness and learner outcomes (Cauet, Liepertz, Kirschner, Borowski, & Fischer, 2015).

Similar to this study, researchers (including Ramnarain & Schuster, 2014) have noted gaps in the competencies of teachers in relation to practical work. Specifically, Ramnarain and Schuster (2014) noted that a shortfall in teacher competencies contributes in the use of confirmatory practical work in some science classrooms. In addition, actual or expected failures in the implementation of practical work involving guided and open inquiry have been blamed on the lack of aspects of content knowledge (Zion et al., 2007), the lack of behaviour management skills (Kidman, 2012), pedagogical constraints (Hofstein & Lunetta, 2004), in addition to beliefs about classroom organization that hamper learning about and doing inquiry (Trumbull et al., 2006). However, these gaps in teacher competencies are not linked to specific intrinsic teaching challenges as is the case in this study. Also, though there have been studies (such as E. A. Davis, Petish, & Smithey, 2006; Nivalainen et al., 2010; Ramnarain, 2016) involving the intrinsic teaching challenges that teachers face in science classrooms in secondary schools, few of these studies (including Akuma & Callaghan, 2016) have characterised the intrinsic challenges. In this study, as reflected in Table 3, we systematically characterised and clarified specific intrinsic teaching challenges associated to the design and implementation of IBPW. That being said, Akuma and Callaghan (2016) characterised intrinsic teaching challenges linked to the improvisation of science education equipment and materials in schools into preparation (planning)-phase and implementation-phase challenges. In this study, we also identified evaluation-phase challenges, in addition to characterising implementation-phase challenges. Thus, this study enhances the characterisation of intrinsic teaching challenges inherent in practical work in secondary schools. The detailed characterisation of any phenomenon assists in revealing the complexity of the phenomenon (Rozenszajn & Yarden, 2014), in addition to providing coherence and value (El-Deghaidy et al., 2015). In this regard, this study also complements the work of Akuma and Callaghan (2017) who characterised extrinsic teaching challenges linked to the design and implementation of IBPW. We have thus enhanced the picture of teaching challenges linked to the design and implementation of IBPW. In this way, the study has contributed in responding to calls for a more comprehensive description of the challenges that science teachers face when preparing practical work (Nivalainen et al., 2010), and a clear description of the challenges inherent in the implementation of inquiry-based approaches in science classrooms (B. A. Crawford, 2007).

Considering the discussion in the preceding paragraph, the results of this study have theoretical and practical implications. However, the study also has research-based implications. Regarding the practice-based implications, the results suggest in line with Lunetta et al. (2007), that ‘‘[m]uch more must be done to assist teachers in engaging their students in school science laboratory experiences in ways that optimize the potential of laboratory activities as a unique and crucial medium that promotes the learning of science concepts and procedures, the nature of science …’’ (p. 433). However, the results identify in a systemic manner, specific challenges and corresponding teacher competencies that need attention as reflected in Table 3. Even experienced teachers tend to need prolonged professional support in order to effectively implement inquiry-based tasks in their classrooms (Lederman & Lederman, 2012). In this regard, and in addition to support, external sources of stimulus and information are needed considering the external domain of the Interconnected Model of Teachers’ Professional Growth (IMTPG, Figure 1). The results of this study as reflected in Table 3, suggest that teacher support in relation to the intrinsic challenges linked to the design and implementation of IBPW can be framed using the Initiation, Planning and Implementation phases of the Science Laboratory Instructional Design (SLID) model. This is with the incorporation of the engagement, exploration, explanation, elaboration and evaluation (5e) model in the Implementation phase. The results contain intrinsic teaching challenges in several phases of each of these models. The incorporation of the 5e instructional model in professional development efforts has enabled teachers to design their own inquiry-based science lessons (Zwiep & Benken, 2013). Based on the IMTPG, the teachers also need to enact the lessons they design in the classroom, in addition to reflecting upon their experiences. This could result in changes in the domain of consequence of the IMTPG, in terms of a reduction in intrinsic teaching challenges linked to the design and implementation of IBPW. Based on the IMTPG, the teacher support should be provided in line with the constraints and affordances of the professional environment.

Within the framework of the discussion in the preceding paragraph, the different intrinsic teaching challenges linked to the design and implementation of IBPW characterised in this study, could be addressed by professional development providers, with reference to the literature on the design and implementation of inquiry-based science education. We illustrate this in relation to the challenge teachers experience regarding the formulation of inquiry questions (planning-phase challenge) and also when engaging in formative teacher-learner interactions (implementation-phase challenge). Regarding the challenge being posed by the formulation of inquiry questions, the literature offers possible ways for increasing teacher competencies in this regard. The ways include providing teachers more focused and just-in-time practice on the formulation of inquiry questions (Hofstein, Navon, Kipnis, & Mamlok-Naaman, 2005), coupled with personalized feedback (Zion & Mendelovici, 2012). In one professional development effort in this light, teachers were asked to identify a thought provoking scientific phenomenon, and then to write a proposal for open inquiry about this phenomenon that is similar to the tasks required of their students (Zion & Mendelovici, 2012). Regarding engaging in formative teacher-learner interactions and for meaningful learning, teachers need to purposefully use questioning to elicit and foster learner thinking (Harris & Rooks, 2010). They need to pose and promote questions that, for example, help clarify inferences and observations, apply or extend ideas, in addition to justify responses (Minstrell & van Zee, 2003). In this regard, the teacher needs to ensure that the conversation is directed at reaching essential science ideas and practices (T. Crawford, Kelly, & Brown, 2000).

The theory-based implication of this study lies in the extension of the categorisation of intrinsic teaching challenges of Akuma and Callaghan (2016) with the elaboration of the three of the categories that they identified. For example their preparation-phase challenges category has been split in this study into the initiation- and planning-phase challenges categories. As a result, we now have a better appreciation of the complexity of teaching challenges linked to the design and implementation of IBPW.

The detailed characterisation of a phenomenon also assists in uncovering knowledge within specific categories (Abell, 2008). In this light, this study suggests avenues for further research. For example, only one study identified an elaboration-phase intrinsic challenge. Specifically, Lunetta et al. (2007) noted that teachers generally do not give learners the opportunity to apply their learning experience to other phenomena. The elaboration and application of learning leads to enhanced learner understanding (Hofstein & Lunetta, 2004; Hofstein et al., 2005). Also, the results of this study do not contain intrinsic challenges linked to the feedback phase of practical work design. It is not clear whether science teachers hardly encounter intrinsic challenges in the elaboration and feedback phases of practical work design (and what we could learn from this), or researchers have paid less attention to these phases of IBPW in past studies. These questions could be incorporated in future studies. This is in addition to gathering ways for addressing the different gaps in teacher competencies identified in this study. Moreover, given the complexity of the intrinsic challenges reflected in Table 3 and thus the complexity of the professional development task, we also recommended the development of an associated professional development framework. This is "an abstract artefact serving as a blueprint of the associated professional development process and consisting of concepts, assumptions, principles, values and practices linked to the processes, means and ways through which the desired professional development outcomes may be achieved" (Akuma, 2017, p. 74).

We see that, in order to better enhance science teachers regarding the diverse intrinsic challenges they could encounter in the context of the design and implementation of IBPW, the efforts of researchers and professional development providers are needed as seen in the preceding discussion. However, school managers (administrators) strongly influence whether science teachers receive the professional development they need in order to develop their knowledge and skills (Singer, Hilton, & Schweingruber, 2005). This makes them role players also. Thus, when addressing the intrinsic challenges, a multi-stakeholder perspective is needed. Though a significant amount of effort is thus required, this is worthwhile if we consider the point noted by Nompula (2012) that some learners have limited access or fewer opportunities to engage in inquiry-based lessons as a result of their teachers possessing inadequate relevant knowledge and skills in performing such lessons.

Acknowledgements

The authors thankfully acknowledge the excellent comments and suggestions provided by the anonymous reviewers, in addition to the editors, Dana Zeidler and Saouma BouJaoude, after carefully reading the earlier versions of this paper. The comments and suggestions enabled us to significantly improve the paper.

Conflict of Interest Statement

We are not aware of any financial interests regarding this research or any financial benefits that could result from the use of the data.

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Appendix: Coding sheet for articles included in this literature review

Article / Aspect involve	1. Allchin, Andersen, and Nielsen (2014)	2. Blanchard et al.	3. Childs et al. (2012)	4. Donnelly et al. (2013)	5. Dudu and Vhurumuku (2012)	6. Gengarelly and Abrams (2009)	7. Gott and Duggan	8. Harris and Rooks (2010)	9. Hasson and Yarden (2012)	10. Katchevich, Hofstein, and Mamlok-Naaman	11. Kennedy (2013)	12. Kidman (2012)	13. Kind et al. (2011)	14. Kipnis and Hofstein (2008)	15. Ottander and Grelsson (2006)	16. U. Ramnarain (2011)	17. Ramnarain (2014)	18. Ramnarain (2016)	19. Ramnarain and Schuster (2014)	20. U. D. Ramnarain (2011)	21. Ritchie et al. (2013)	22. Ruhrig and Höttecke (2015)	23. Ruiz-Primo and Furtak (2007)	24. Rutten, van Joolingen, and van der	25. Sadeh and Zion (2012)	26. Toplis and Allen (2012)	27. Van Rens, Pilot, and Van der Schee (2010)	28. Zion et al. (2007)	29. Zion and Mendelovici (2012)	
Data collection method(s) ^{a}	h	e	a and b	a, b, and d	a, b, c, d, e and g	a and c	h	h	c and e	a, b, and c	h	a and d	b and c	a, b and c	a, c, and d	a and b	a and d	a and d	a and d	a and b	a, b	a	b and e	h	d	h	a, b, and c	a and c	h	a=16 b=11 c=9 d=7 e=4 f=0 g=1 h=7
Study location ^{b}	X	iv	ii	iii	i	iv	X	X	ii	ii	X	v	iii	ii	iii	i	i	i	i	i	v	iii	iv	X	ii	X	iii	ii	ii	i=6 ii=7 iii=5 iv=3 v=2
Science subject (s) taught by participating teachers ^{c}	X	○	“Unspecified”	□	●	○, □, ●, ■	X	X	■	□	X	□, ■, ◊	“Unspecified”	□	■	○	●	○, ●	●	“Unspecified”	◊	“Unspecified”	●	X	■	X	□	■	X	■ = 6 □ = 6 ◊ = 2 ● = 6 ○ = 4 “Unspeci ied” = 3
Type of inquiry involved ^{d}	X	II	II	II	II	I, II, and III	X	X	III	III	X	II and III	II	III	“Unspecified“	III	X*	II	II	I and III	II and III	X*	I and II	X	II and III	X	III	III	I, II, and III	I=5 II=14 III=12

Scientific practices incorporated [e]	X	A, C(i), C(ii), D, and F*	C(i), C(ii), D, and F*	C(i), C(ii),	A, C(i), C(ii), D, F*, G and H	A, C(i)	X	X	A, C(i), C(ii)	A, C(i), C(ii), F*	X	A, C(i), C(ii), D, F* and H	C(i), C(ii), D, E, F, G, and H	A, C(i), C(ii), D, F*	A, C(i), and C(ii)	A, C(i), C(ii), D and H	C(i), D, and F*	A, C(i), C(ii), D, F/F*, H	"Unspecified"	C(i), C(ii), D, and F	A, C(i), C(ii), F* and H	"Unspecified"	C(i), C(ii), D, E, and F	X	A, C(i), C(ii), D, and F*	X	A, C(i), C(ii), D, and F*	A, C(i), C(ii), D, and F*	A, C(i), C(ii), D, and E	A=15 C(i)=21 C(ii)=19 D=15 E=3 F=4 F*=12 G=2 H=6

Legend (continued on next page):

X = not applicable as paper does not contain description of an instructional sequence (case of almost all the review articles)
X* = not applicable (for example when classroom activities are described as investigations without mentioning type of inquiry involved)

[a]
a = Interview
b = Observation
c = Artefacts
d = Survey
e = Learner assessment
f = Experiment
g = Field notes
h = Literature review

[b]
i = Africa
ii = Asia
iii = Europe
iv = North America
v = Oceania

[c]
■ = Biology
□ = Chemistry
◊ = Physics
● = Physical sciences
○ = Other sciences (Environmental sciences, Life sciences, Natural sciences, forensics, and Biotechnology)

[d]
1 = Level 1 (Structured inquiry)
2 = Level 2 (Directed inquiry)
3 = Level 3 (Open inquiry)

[e]
A = Asking questions
B = Developing and using models
C = (i) Planning and (ii) Carrying out investigations (numbering added)
D = Analysing and interpreting data
E = Using mathematics and computational thinking
F = Constructing explanations
G = Engaging in evidence-based arguments
H = Obtaining, evaluating and communicating information